



# Impact of jet fan ventilation systems on sprinkler activation



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## ABSTRACT

Jet fans are increasingly preferred over traditional ducted systems as a means of ventilating pollutants from large spaces such as car parking buildings.

Outside of tunnel applications jet fans are considered to have limitations as means of smoke control. This is because their effectiveness is limited without side walls and they de-stratify the smoke layer. Jet fans can however, aid post-event in smoke clearance under the control of the attending fire brigade.

The prudent fire mode strategy in those jurisdictions where jet fans are not used for smoke control is for the ventilation system to shut down on a fire alarm signal.

The problem lies in the jet fans receiving that signal. A fire has three basic signatures; heat, smoke, and light.

Large car parking buildings may be sprinkler-protected. Sprinklers operate on the heat signature. A jet fan is assumed to disrupt this signature by forcing the plume of heat downstream and diluting that plume with cool air. This may delay sprinkler activation.

In terms of the smoke signature, the presence of pollutants such as carbon monoxide that could be detected by a specialised detector, are the same signals that would cause a jet fan to increase its flow in normal mode. The response to a smoke signature is contradictory between the desired normal-mode reaction to speed up and the fire-mode reaction to shut down.

This leaves light. Fires are very rich across the non-visible light spectra and flame detectors are an effective way to provide a fire signal independent of the normal-mode operation of the jet fans. However, the cost-benefit of installing flame detectors in addition to sprinklers is questionable.

A series of detailed computational analyses are therefore undertaken to quantify the impact of the jet fans on delaying sprinkler activation on a typical car park sprinkler arrangement. This article assumes the perspective of a jurisdiction where the fire mode strategy is for the fans to shut down. However, the sprinkler delay will also be of interest where the fire mode strategy is to continue operating.

Once sprinkler activation had occurred a fire signal is assumed to have been generated to shut down the jet fans. Separate evaluations can then be made as to whether the delay was acceptable or not, dependent upon to the specific building geometry.

The results indicate that for a fast-growing design fire, sprinkler activation occurred at ~180 s with the jet fans off and at ~210 s with them on: an increase of  $\leq 30$  s. A separate analysis was undertaken for the case-specific egress safety margin. Comparing the two, it was concluded, that the impact of jet fans upon sprinkler activation was not significant. It

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was further established that the smoke disturbance due to the jet fan flow did not adversely affect the visibility for those escaping.

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## Introduction

This paper discusses a case study undertaken on an underground car park building of approximately 30,000 m<sup>2</sup>. This paper focuses on the sprinkler delay which is typical of many geometric arrangements. The safety margin is building specific and is not presented here for the sake of brevity and to keep the case study general in application.

### *Contemporary research into car park fires*

In 2010 BRE published a comprehensive research report titled 'Fire Spread in Car Parks' [1]. The overall aim of the project was to gather information on the nature of fires involving modern cars and to use this new knowledge as a basis, where necessary, for updating current guidance in Approved Document B [2].

The key findings from the study are:

- The number of fires in car parks each year is about 260 per year. This represents a very small percentage of all fires in the UK and the trend is downward.
- Of these fires in car parks, about 50% did not start in a car.
- Many car fires are deliberately lit.
- Most fires in car parks do not spread (to a car or another car).
- About seven people are injured in car park fires each year and there are very few fatalities; on average less than one per year.
- Fires in car parks for which the building is classified as 'car park' show an injury rate which is low compared with other occupancy types.
- Fires which spread to involve more than one car can sometimes result in significant structural damage.
- Despite concerns, there is very little evidence (and no substantiated evidence) to show that cars fuelled by LPG are a particular danger in fire.
- The experimental programme demonstrated that where a fire starts in a car which is well-ventilated (i.e. open windows), very fast growing and severe fires have resulted, leading readily (when sprinklers are not present) to fire spread to all nearby cars and potentially, all cars in the car parks.
- The experimental programme also demonstrated that where a fire starts in a car which is poorly-ventilated (i.e. closed windows), the fire may go out, and has demonstrated that fires in engine compartments will grow slowly.
- These results largely account for the very few car park fires which cause substantial or significant structural damage.
- The effectiveness of sprinklers in limiting a fire to a single car has been demonstrated.
- There are no cases to date in the UK of structural collapse of a car park due to fire.

### *Description of the system (normal-mode)*

Ventilation of the case study car park is achieved through mechanical exhaust at each level with make-up air provided from natural ventilation openings in the perimeter and transported via impulse ventilation from jet fans.

The jet fans provide advantages through elimination of air distribution ductwork within the car parks and reduction of supply and exhaust air flow resistance, thereby reducing the associated fans energy consumption.

The normal-mode criteria is to ensure minimum airflow velocities are maintained throughout the car park areas and that a maximum carbon monoxide concentration is not exceeded. Carbon monoxide monitoring control systems are provided to vary the fan speeds.

### *Description of the system (fire-mode)*

As described above, this article assumes shut down in fire mode. Under normal operation the jet fans increase air flows upon detection of carbon monoxide. Unfortunately, carbon monoxide is a common product of fire and so there are contradictory system objectives for the fan to both speed up and shut down.

Alternative methods of generating a fire signal to shut down the jet fans were considered.

- Heat sensing devices suffer from the same delay as the sprinklers since they operate on the same principle.
- Smoke sensing devices are not effective as in normal mode operation the jet fans activate at a threshold many times lower than would be expected in a fire and dilute concentrations.
- Light sensing devices along the fan line of sight will detect fires at an early stage. The UV ranges are not notably effective in smoky environments but the IR are effective.

## Analyses

Computational Fluid Dynamics or CFD is used to solve fundamental flow equations, and has been applied to modelling of fire and smoke behaviour for over 20 years. For a comprehensive discussion of CFD as applied to fire refer to Chapter 3–8 of the SFPE Handbook of Fire Protection Engineering [3].

The suite of CFD computer models used in these fire-mode calculations are FDS [4] using the PyroSim [5] pre-processor and Smokeview [6] visualisation.

FDS is not specifically ‘validated’ for jet vent air flows. Other proprietary software could model that aspect more accurately. However, the analysis is not solely about air flows, it is three-part; fire plume, sprinkler activation and air flow. FDS is considered to be superior in those other two aspects. It should also be noted that CFD models in general are better predictors than empirical models. They are more fundamentally based. This does not mean they are perfect predictors however they are good predictors. These analyses are comparative; fan off and fan on and this reduces uncertainty.

For expedience of calculation, the model domain is deliberately small to limit the number of calculations, yet large enough to be representative. The space modelled represents an area of the car park of 20 m by 20 m by 4 m high and contains the jet fan, the fire source and an array of sprinklers. The boundary conditions are concrete floor and slab above with open sides to represent an infinite space. A plan view of the model domain is shown in Fig. 1.

Two cases are modelled, with the jet fans off or on:

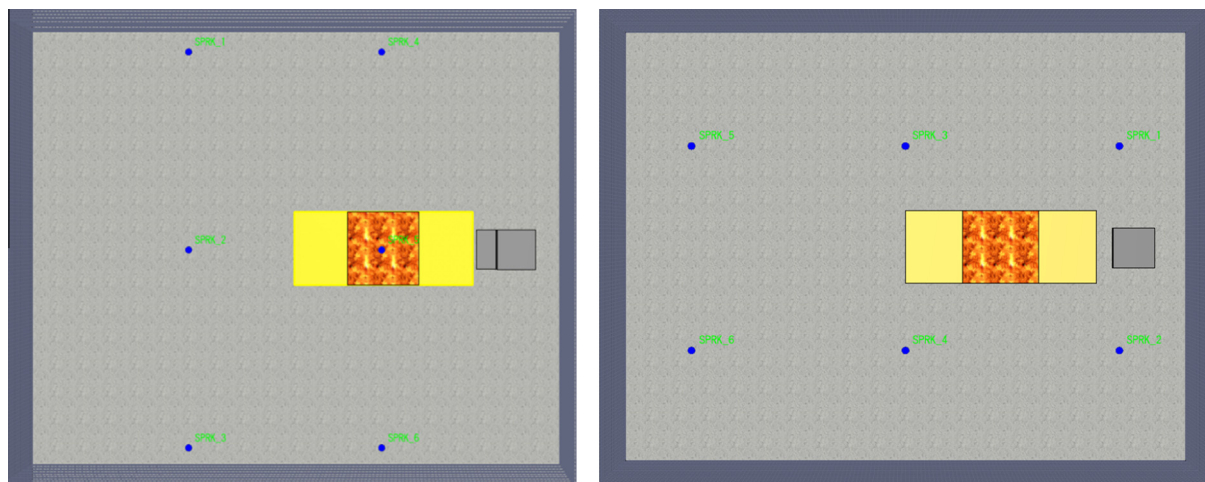
- *Case A:* Sprinklers are in-plane with the jet fan’s centreline. This is the ‘worst case’ from a disruption point of view as it exposes the sprinklers to the maximum centreline velocity, and
- *Case B:* Sprinkler array is rearranged to be as far as possible from the jet fan centreline. This is the proposed configuration as it places the sprinklers furthest from the centreline velocity.

A flow rate of  $1.35 \text{ m}^3/\text{s}$  was modelled through a nozzle 900 mm wide by 100 mm high. This is the maximum flow rate and its use is conservative as it leads to the greatest sprinkler delay. This centreline velocity at the outlet is approximately 15 m/s maximum. The nozzle directs air flow downward by  $\sim 7^\circ$  however the initial cases were simplified and a jet stream at  $0^\circ$  was assumed. The inclined air flow is picked up in the sensitivity cases.

Where possible it is recommended that fans are installed over the roadways, as this is where the motor vehicle pollutants are most prevalent. This is a positive feature for the fire-mode case, since car fires are assumed to predominantly occur in stationary vehicles. This means that most fire locations will occur more remotely from jet fan locations than the cases modelled, meaning less potential for interference.

The choice of design fire is derived from the British Standard BS 7346-7 as described in BD2552 [1]. This is a  $5 \text{ m} \times 2 \text{ m}$  source of perimeter 14 m and with a 4 MW HRR. The purpose of the design fires in BS 7346-7 is to size smoke control systems and hence the steady state fire. In this case study a fast  $t^2$  growth rate is assumed. This is more conservative as a steady state design fire would lead to quicker sprinkler activation and system shut-down. The decay phase is ignored. This is modelled in FDS using the heat release rate per unit area (HRRPUA) or ‘burner’.

Petrol was selected as a fuel rather than say a plastic or rubber-based material. Because the HRR\_PUA function is used and because the visibility is directly analogous to other tenability criteria the parameters of importance are the Soot Yield and the Visibility Factor.



**Fig. 1.** Plan view, Case A (L) sprinkler array in-plane with jet fan centreline, and Case B (R) sprinkler array out of plane from jet fan centreline.

The soot yield for petrol of 0.058 kg/kg is also representative of polyethylene 0.060 kg/kg and polypropylene 0.060 kg/kg [7]. The visibility factor of 8 is used since exit signage is light emitting rather than light reflecting which is the default factor of 3 [4].

Having selected the model domain and design fire the grid resolution and source Froude number were checked. For brevity these studies are not included here other than to say;

- Cell sizes between 100 and 400 mm are within the range to adequately resolve plume dynamics with 100 mm selected to provide the finest grid.
- The source Froude number was within the appropriate range to be representative of a buoyant fire.

### Initial results

FDS was used to calculate the predicted sprinkler link temperature. The results of the Case A and Case B arrangements are shown in Fig. 2. For clarity, only the first sprinkler in the array to activate is included.

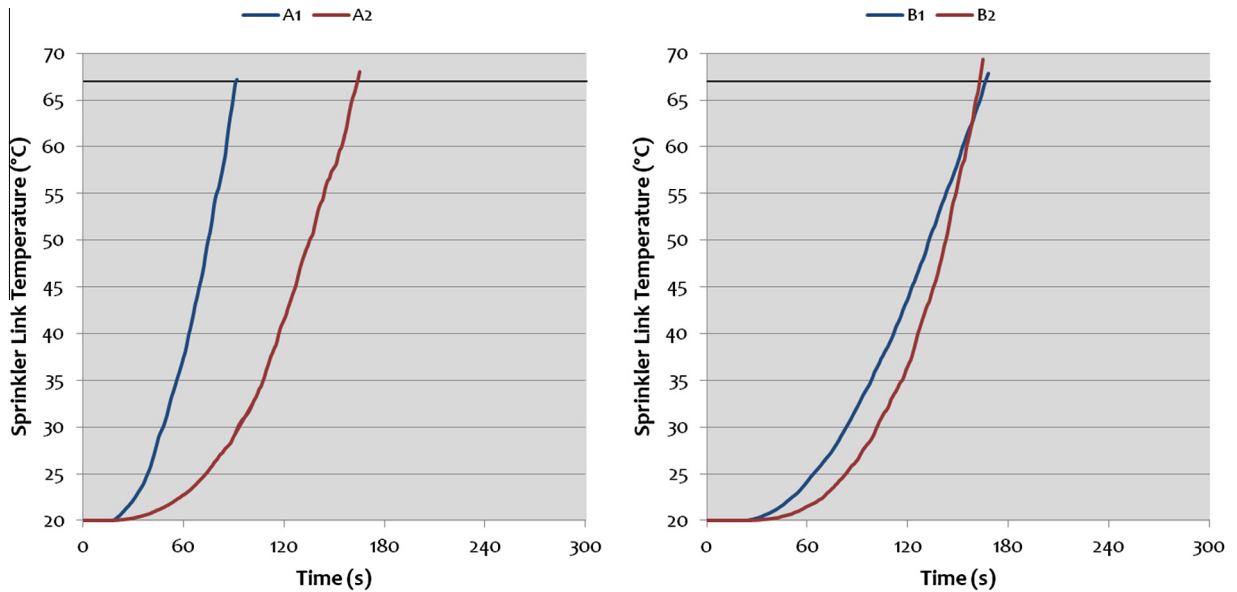


Fig. 2. Effect of jet fan on sprinkler activation, (L) Case A and (R) Case B.

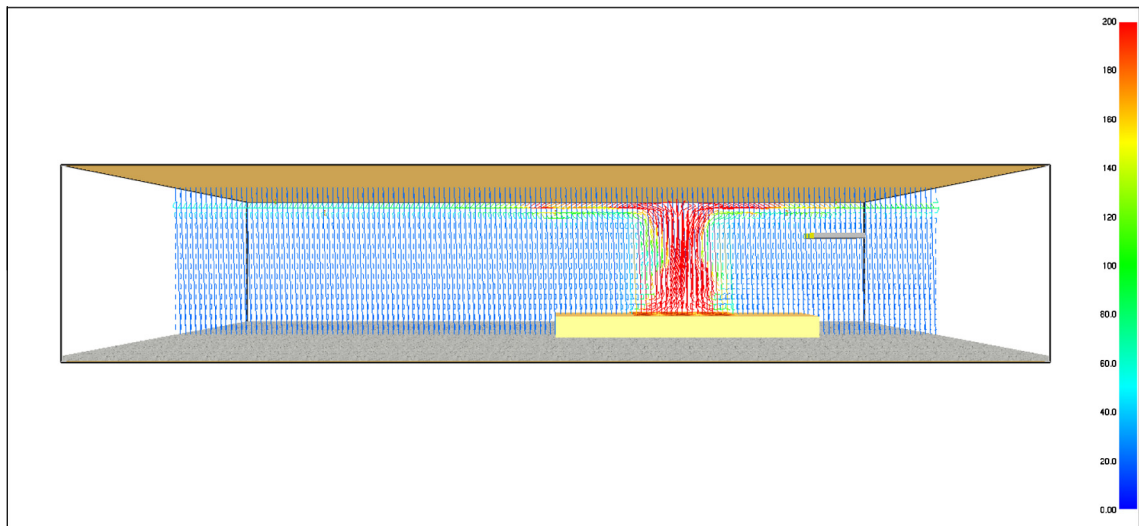


Fig. 3. Temperature vectors Case B1 with jet fan off at 165 s (~activation).

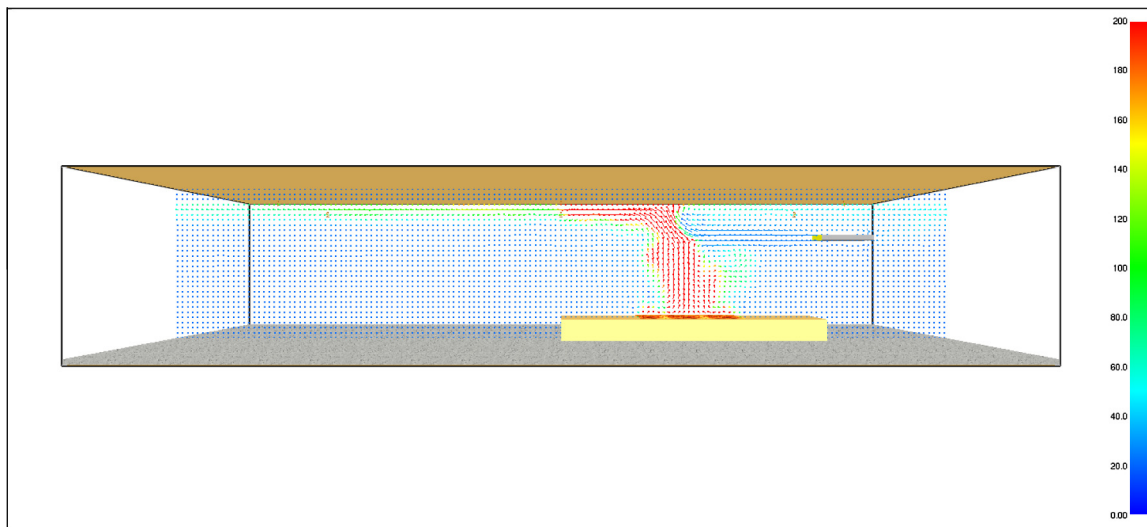


Fig. 4. Temperature vectors Case B2 with jet fan on at 165 s (~activation).

- *Case A*: Sprinkler activation is delayed by  $165 - 92 = 73$  s. It is not the sprinkler immediately above the fire that activates first, but rather the one downstream.
- *Case B*: The sprinkler temperature lags that of the non-operating case as in the early stages of fire growth, but as the HRR increases that lag decreases to the point that there is a negligible activation time delay.

Animations may also be viewed on YouTube at [http://youtu.be/NRd\\_R2W0OkQ](http://youtu.be/NRd_R2W0OkQ), and <http://youtu.be/zhvdVUFP2iw>. In these, it can be observed that in the early stages of fire growth, where the HRR is low, the fire plume leans sharply towards the downstream in response to the effect of the jet fan flow. This straightens as the HRR increase and at about 1000 kW the fire plume has sufficient buoyancy and momentum to penetrate the jet stream. The Case B results are also shown as temperature vectors in the following Figs. 3 and 4 at sprinkler activation.

### Sensitivity cases

Additional analyses were undertaken that tested the sensitivity of sprinkler activation to varying factors. In each Case a pair of analyses are undertaken, i.e.; with (2) and without (1) the jet fans running. The cases are summarised in Table 1.

**Table 1**  
Summary of scenarios.

Scenario	Jet fan	Description
Case A	1 = Off 2 = On	Sprinkler array in-plane with jet fan centreline (the so called 'bad' arrangement)
Case B	1 = Off 2 = On	Sprinkler array out of plane from jet fan centreline (the so called 'good' arrangement)
Case BA	1 = Off 2 = On	Case BA: As per Case B above with the affect of an angled (inclined) air flow modelled
Case C	1 = Off 2 = On	As per Case B but with a shielded fire source
Case CA	1 = Off 2 = On	As per Case C with the affect of an angled (inclined) air flow modelled
Case D	1 = Off 2 = On	As per Case B but with a varied sprinkler height
Case E	1 = Off 2 = On	As per Case B but with a varied growth rate
Case FA	1 = Off 2 = On	As per Case B but the sprinkler array offset forward by 1 m relative to the nozzle and with inclined air flow modelled
Case G	1 = Off 2 = On	A final sensitivity case not to determine sprinkler delay but to determine the disruption to visibility of the jet fans up

Code	Configuration		Jet Fan		Shielded		SPRK AFL(m)		Growth Rate		Inclined		T(s)	$\Delta t(s)$
	Bad	Good	Off	On	No	Yes	High	Lo	Fast	Med	No	Yes		
A1	X		X		X		X		X		X		92	73
A2	X			X	X		X		X		X		165	
B1		X	X		X		X		X		X		168	-4
B2		X		X	X		X		X		X		164	
C1		X	X			X	X		X		X		208	17
C2		X		X		X	X		X		X		225	
D1		X	X			X		X	X		X		200	23
D2		X		X		X		X	X		X		223	
E1		X	X			X	X			X	X		377	84
E2		X		X		X	X			X	X		461	
BA1		X	X		X		X		X			X	177	4
BA2		X		X	X		X		X			X	181	
CA1		X	X			X	X		X			X	203	18
CA2		X		X		X	X		X			X	221	
FA1		X+1	X		X		X		X			X	200	16
FA2		X+1		X	X		X		X			X	216	

Fig. 5. Matrix of results.

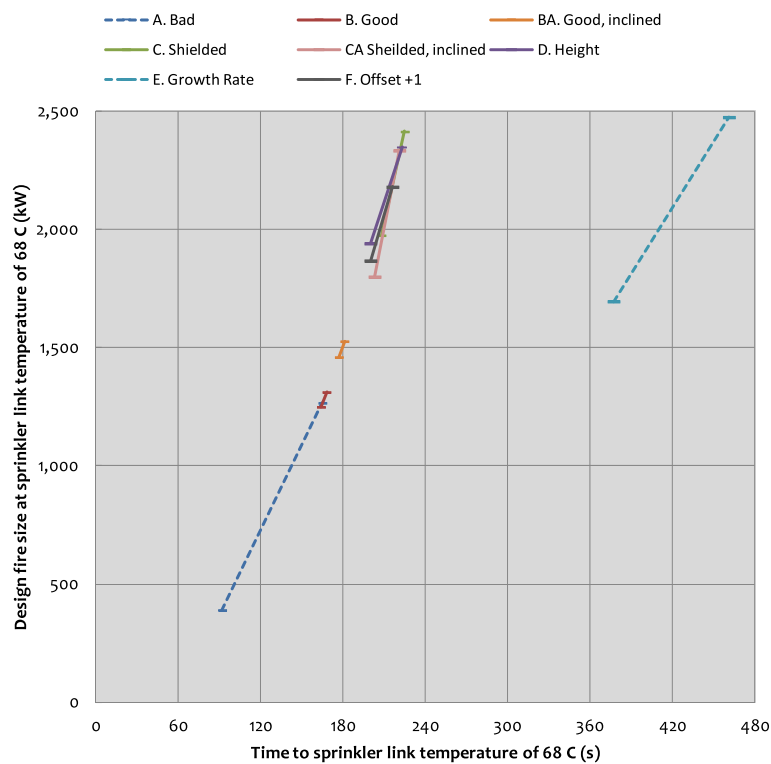


Fig. 6. Collated results, HRR versus time to sprinkler activation.



## Collation of results

The results in terms of time and time-differential to a link temperature of 68 °C are given in Fig. 5 below. The important result is the time-differential recorded in the right-most column. These results are also expressed graphically in Fig. 6.

Problems associated with the delay in Case A can be eliminated by specifying and installing the sprinkler array offset from the centreline velocity. Case E with the medium growth rate is included for illustrative purposes. In the companion egress calculations the ASET assumed a fast  $t^2$  fire. The delay in sprinkler activation is longer for a medium  $t^2$  fire but this also results in a longer ASET.

Cases B, BA, C, CA, D and F are of the most interest. All adopt the optimum sprinkler array arrangement. These all result in a <30 s delay. Note also, that the HRR is less than the 4 MW steady-state fire assumed.

An additional Case G was run to determine the impact on visibility downstream of the fan. This is not related to sprinkler activation but included for completeness. The model was run to 240 s because sprinkler activation occurs at 221 s in Scenario CA2 it is assumed the fans will shut down at about this time. Contrary to worsening the situation, the jet fans improve visibility by diluting the smoke density.

## Conclusions

Fires in car parks are rare events. According to UK research of >3000 car park fires only about half originate in cars. Following an experimental program it was found that:

- Fires in engine compartments will grow slowly.
- Where a fire starts in a car which is poorly-ventilated (i.e. closed windows) the fire will most probably go out.
- Where a fire starts in a car which is well-ventilated (i.e. open windows), very fast growing and severe fires have resulted, leading readily (when sprinklers are not present) to fire spread to all nearby cars.
- The effectiveness of sprinklers in limiting a fire to a single car has been demonstrated.

Ventilation of car parks using jet fans to reduce pollutants is becoming an increasingly popular alternative to fully-ducted systems.

- Jet fans are considered to have limitations as means of smoke control. This is because their effectiveness is limited without side walls.
- Jet fans can however, aid post-event in smoke clearance under the control of the attending fire brigade.

The convention is for jet fans to stop in fire mode. The problems are how and when this is achieved. The generation of carbon monoxide in the early stages of fire will cause the jet fans to increase their speed.

- This causes disruption of the smoke signature by dilution of fire products and makes shut down based on a high concentration of carbon dioxide unreliable.
- Similarly, the increased air flow can disrupt the heat signature by disrupting the fire plume and ceiling jet. This could delay sprinkler activation.

In order to quantify the potential delay to sprinkler activation caused by jet fans continuing to operate sixteen CFD analyses are undertaken to determine whether (i) it is significant and (ii) it detrimentally impacts upon the means of escape in the car park undertaken in a separate companion analysis (not presented here for brevity). The results of the analyses indicate delays of  $\sim \leq 30$  s to sprinkler activation where the sprinkler and jet fans layout was coordinated so the sprinklers are in-plane with the jet fan nozzle. This does not significantly increase the hazard to occupants with the safety margin in the egress design being many times greater than this. Furthermore, the jet fans do not adversely affect the visibility in means of escape.

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